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The objective of this program is to formulate an approximate analytical method for the estimate of penetration depth of a projectile into a target and provide a rational basis to deduce the constitutive equations of the target material at large damage. An array of benchmark cases was simulated, and new statistical methods are developed and discussed.

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PROJECT: DAAH04-95-1-0134

MECHANICS OF LONG ROD PENETRATION INTO CERAMIC TARGETS

Dusan Krajcinovic, PI

Final Report

The thermodynamics of the penetration of a projectile through a target is non-linear, irreversible, non-stationary and far from the equilibrium. This is especially true when the inelastic deformation of the target is traced to the extensive microcracking that eventually leads to crushing and/or localization into microcracks. The available test data are almost as a rule limited to the observations of the crater and measures of penetration length are crater geometry.

The objective of this program was to formulate an approximate analytical method for the estimate of the penetration depth of a projectile into a target and provide a rational basis needed to deduce the constitutive equations of the target material at large damage. Traditional local continuum models and strain rate dependent constitutive relations are not applicable since the deformation is far from the equilibrium and damage large. Moreover, the test data at given strain rates are not available. Furthermore, deterministic measures of deformation and damage patterns in materials with microstructural disorder may not always be useful.

The only realistic strategy is to approximate the material by a lattice made of continuum particles interconnected by links. The size of continuum particles; which consist of many molecules, is determined by micromechanical considerations. For example, a particle can be as large as the smallest volume that cannot be fractured by compressive stresses. The statistics of the lattice morphology and link properties are determined from the microstructural properties of material.

An array of benchmark cases is simulated to check the model and simulations at large strain rates to gain confidence in selection of parameters and microstructural statistics. The Taylor or rigid-anvil test is used to check for the distribution of fragment sizes, relative shortening of the projectile, stress wave features, disturbance propagation velocity and temperature field. Simulations of the planar impact are used to model spalling, shock wave attenuation and to formulate the proper initial strain-rate that keeps the strain rates homogeneous afterwards. Further biaxial compressive and tensile tests are performed to observe damage patterns and optimize the time-step.

The final set of simulations is focused on determination of radial forces needed to drive the expansion of a circular void within a brittle material at a given rate. The effective material parameters, stress, strain and damage fields, kinetic, potential energy and energy consumed by the formation of new internal surfaces are used to deduce the constitutive relations. These constitutive equations are then used to formulate a

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surprisingly simple analytical model. The fit between the simulation data and analytical solution of the model is exemplary.

The simulation strategy, involving mapping the lattice on the material, bench-mark problems, identified universal trends, interpretation of simulation data, and statistical methods used in the model, are carefully discussed in the papers published by D. Krajcinovic and S. Mastilovic (whose complete his theses on this work).

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Project: DAAH04-95-1-0134

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